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Improving Sound-Absorption Properties of Porous Concrete Materials

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ABSTRACT

Different methods of improving sound-absorptive properties of porous concrete-based materials, to be used as noise barriers, were investigated including

a/ changing the material composition and thickness,

b/ incorporating resonator cavities in the form of resonator tubes or Helmholtz resonators, and

c/ sealing one face of homogeneous materials.

Two generic material types were evaluated; a two-layer system consisting of an absorptive layer with a rigid backing, and a single layer of homogeneous porous concrete. The investigation encompasses both analytical analyses and laboratory measurements using both the impedance tube and the reverberation room measurement methods. The results indicate that one of the most promising methods to improve sound-absorption quality of porous concrete-based material is sealing one face of the material.

ACKNOWLEDGEMENT

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1/ INTRODUCTION

There is an increasing need for sound-absorptive materials suitable for use as highway noise barrier. The use of sound-absorptive materials can significantly improve the performance of parallel highway noise barriers [1] and, in the case of single barriers, it can substantially reduce the amount of sound reflected by the barrier to the opposite side of the highway. Presently, all sound-absorptive barriers, that is, barriers which absorb more sound energy than they reflect, or partially sound-absorptive barriers built in Ontario, have utilized Portland cement-based materials. This may be attributed to the harshness of the highway environment and to the cost considerations.

The objective of this study is to evaluate and improve sound-absorptive properties of the Portland cement-based materials which are commercially available. Two generic types of these materials were investigated:

a) A two-layer system consisting of an absorptive layer, formed by wood fibres bonded together by Portland Cement, and a high-density concrete layer. The material selected for the study was Durisol-- produced by Durisol Materials Ltd. Durisol is a light-weight building material made of chemically mineralized and neutralized softwood shavings bonded together under pressure with Portland cement.

2) A single layer of homogeneous porous concrete using mineral aggregates bonded with Portland cement. The material selected for this study was obtained from Evercrete Ltd. This material contains sand and limestone screening aggregates and has the porosity of about 20%.

2/ SOUND ABSORPTION MEASUREMENTS

The sound-absorption measurements were performed using two methods, the impedance tube (IT) method and the reverberation room (RR) method as specified in References 2 and 3, respectively. The IT measurements were done at the Ontario Ministy of Transportation and Communications Research Laboratory using standard instrumentation manufactured by Bruel and Kjaer. The sample diameter was approximately 100 mm and the small gap between the sample and the impedance tube was sealed with a thin ring of plasticine. The RR measurements were performed at the Division of Building Research, NRC, Ottawa, and at the Domtar Research Centre, Senneville, Quebec.

All measurements should have been, preferably, performed at one facility using only the RR method since the use of different testing facilities can contribute to measurement errors [4] and, more importantly, the RR method is the most appropriate testing method for hard materials, such as those used in this study, which may exhibit a resonant sound-absorption [5]. The RR measurements at the two external facilities were necessitated by the availability of these facilities. The impedance tube measurements were used because of the considerable number of samples tested. The costs of producing and testing dozens of large samples required for the RR method would be prohibitive (the minimum recommended surface area for the RR method is about 4.5 m^2). Also, given the nature of the materials tested, it would be difficult to produce large samples with uniform properties, such as porosity or surface roughness.

3/ COMPARISON OF TESTING PROCEDURES

3.1/ Two-Layer Panels

The sound-absorption coefficients of the 2-layer system measured by the RR and IT methods are compared jointly in Figure 1 even though the coefficients obtained by the IT method are normal incidence sound-absorption coefficients and the coefficients obtained by the RR method are in sabines. The two-layer system consists of 7.5 cm thick Durisol material bonded to high density reinforced Portland cement concrete backing, approximately 1.9 cm thick. The results of the RR measurements reported in Figure 1 were obtained with the sample panels laying on the floor of the reverberation room and also standing in an upright position.

According to Figure 1, the two sample positions tested by the reverberation room method, as well as the impedance tube method, produced similar results which indicate that the sound-absorption of the two-layer panels occurs both in porous and resonant ways. The position of the panels in the RR is not critical and the IT measurements realistically resemble those obtained in the reverberation room.

3.2/ One-Layer Homogeneous Panels

The results of sound-absorption measurements of homogeneous porous concrete panels, obtained by the two mesurement methods, are compared in Figure 2. The panels are self-supporting (without a rigid backing) and the presence of resonant absorption is evident only if the rigid backing is artificially created by the floor of the RR (when the panels are laying on it) or by the IT holder when the materials is measured in the tube. Thus, the proper testing procedure for this material is to have it in standing position in the RR. However, as indicated before, the IT method was also used for this material in order to evaluate relative performance of different material modifications with the intention to test the most promising ones later in the reverberation room.

4/ METHODS FOR IMPROVING SOUND-ABSORPTION

The following methods for improving sound-absorption properties of the Portland cement concrete-based materials were investigated.

1/ changes in thickness of the sound-absorbing layer of the two-layer panels and in the mix composition of the single-layer panels;

2/ Use of resonator cavities - resonator tubes and Helmholtz resonators;

3/ Application of rigid backing to homogeneous single-layer panels.

Whenever possible, both analytical and experimental approaches were used. A brief description of the results achieved by these methods and their limitations is given below.

4.1/ Changes in Thickness and Material Composition

Since the presence of the sound-absorbing layer in the 2-layered panels is not required for structural support, the thickness of the layer can be changed. By varying the thickness of the absorptive layer, it is possible to influence both the amount of sound-absorption and the position of the resonance frequency (Figure 3). The relationship between the thickness of the absorptive layer and its overall sound-absorption, expressed in terms of A-weighted sound-absorption coefficient α_A is shown in Figure 4. The coeffecient α_A, when multiplied by 100, gives the percentage of the A-weighted energy equivalent sound level which would be absorbed by the material assuming a typical highway traffic noise spectrum [6]. Thus, α_A provides a single-number index for an easy and accurate comparison of the sound-absorption effectiveness of the highway noise barrier materials.

According to Figure 4, after the thickness of the absorptive layer reaches about 4.5 cm, any additional increase in its thickness results in only marginal improvement of α_A. Also shown in Figures 3 and 4 are calculated sound-absorption coefficients for specific assumptions of flow resistivity, porosity and structure factor of the Durisol material.

Using pressure and velocity equations for a sound wave travelling through a medium and appropriate boundary conditions, the absorption characteristics of the medium can be determined. Considering three mediums backed by a rigid wall (Figure 5), the following ratio of the reflected and incident pressures can be obtained:

$$\frac{B_o}{A_o} = \frac{(B_1/A_1)Z_a - Z_b}{Z_a - (B_1/A_1)Z_b} \tag{1}$$

where: $$Z_a = Z_1 + Z_o \tag{2}$$

$$Z_b = Z_0 - Z_1 \tag{3}$$

$$\frac{B_1}{A_1} = \exp(-2b\ell_1)\ \frac{\exp(2jk_1\ell_2)(Z_2 - Z_1) + (Z_2 + Z_1)}{\exp(2jk_1\ell_2)(Z_2 + Z_1) + (Z_2 - Z_1)} \tag{4}$$

k_1 = wave number (angular frequency/speed of sound)
b = propagation constant [7] and other terms as defined in Figure 5.

The absorption coefficent is defined as

$$\alpha = 1 - \left| \frac{B_o}{A_o} \right|^2 \tag{5}$$

The similarity between the Equations 1 to 4 and Equation 1 in Reference 7 is recognized. However, the Equation 1 in Reference 7 contains several typographical errors.

The analytical approach based on the fundamental material properties, while promising (in view of the apparent agreement between the measured and calculated values given in Figures 3 and 4) could not be effectively pursued because of the unavalability of equipment for airflow resistance measurements [8].

To improve sound-aborption properties of homogeneous concrete materials, a separate study was made which attempted to relate material characteristics, such as specific gravity and porosity, with sound-absorption. Data

for the 10 samples included in the study are summarized in Table 1. The results were rather disappointing in that no significant correlation was obtained between the porosity and sound-absorption coefficent α_A even though some was expected. However, a statistically significant correlation was obtained between surface roughness, measured on a subjective scale, and absorption (Figure 6). This leads to suggest that the way in which the pores are connected to the surface is more important than the amount of pores i.e., porosity. Additional research is required to evaluate the effect of different aggregates (shape and size) and other factors, such as strength, which were not included in this study.

4.2/ Use of Resonator Cavities

4.2.1/ Resonator Tubes

Sound-absorption of resonator tubes occurs primarily due the tube resonance when the sound wave leaving the tube cancels the incoming wave. For resonance to occur, the tube length (disregarding the end correction factor) must be an odd multiple of $\lambda/4$ where λ is the wavelength. The wave amplitude is also attenuated by the viscous friction between the wall of the tube and the air in the tube. However, this attenuation is considered negligible for tubes with radius greater than about 0.2 cm and length shorter than 6 cm [9].

As an example of many resonator tube arrangements evaluated, Figure 7 shows that a significant improvement in the sound-absorption of homogeneous layer of porous concrete can be achieved by creating holes acting as resonator tubes. The improvement is highest at the resonance frequency calculated at 1888 Hz. The calculation was based only on the resonant absorption [9]. The measured and calculated values agree quite well for frequencies near the resonance. For other frequencies, the characteristics of the material itself predominate and the increase in absorption may be attributed to the increase in the total effective area of the sample.

While the sound-absorption of porous concrete materials can be significantly improved by creating resonator tubes, the field application of the resonator tubes requires careful consideration of their impact on

durability, strength and sound transmission of the weakened panel. Also, considering the predominant highway traffic noise frequency of about 550 Hz, the length of tubes to achieve resonance and consequently the panel thickness is relatively large, about 15 cm.

4.2.2/ Helmholtz Resonators

Unlike the tube resonators which absorb sound predominantly by radiation cancellation, Helmholtz resonators absorb sound also by frictional absorption due to the movement of air mass in the neck (aperture) of the resonator. Results obtained from two Helmholtz-type slot resonators incorporated into a layer of porous concrete material are shown in Figure 8. The advantage of this type of resonator is that it can be incorporated into a relatively thin panel and designed so that its resonance absorption coincides with the predominant component of the highway traffic noise frequency spectrum. Figure 8 also shows that the sharp resonant absorption peak may be somewhat blunted and spread out by filling the resonator chamber with fibreglass. As with the resonator tubes, use of this system for highway barriers would be conditional on the strength and durability characteristics of the weakened panels.

4.2.3/ Application of Rigid Backing

As discussed in Section 3.2 and shown in Figure 2, the addition of an apparent rigid backing created by the reverberation room floor to a porous homogeneous material induces resonant absorption. In order to verify this phenomenon and to utilize it in a practical way, a 3.8 m^2 sample of porous homogeneous concrete panel was tested by the reverberation room method in a standing position without any backing and with two types of backing -- a) 1.9 cm thick vinyl-coated gypsum wallboard attached to one side of the panels and b) a heavy coat of Betonite paint on one side of the panels (Betonite is an acrylic-silicone emulsion manufactured by Sternson Ltd.).

While the addition of the gypsum wallboard does not have any significant practical application for the outdoor noise barriers, it shows that it can substantially increase sound-absorption of the panels, particularly at the induced resonant frequency of 500 Hz (Figure 9). The sealing of

one face of the panels (the face away from the noise source) with a concrete paint or Portland cement concrete slurry may be inexpensive and a practical way to increase sound-absorption of the panels. Figure 9 shows that this method can approximately double the sound-absorption coefficient of the original sample at the frequency range of 400 to 630 Hz, which is the predominant frequency range of highway noise.

5/ CONCLUSIONS

1/ The thickness of the absorptive layer of the two-layer panels should be optimized for highway noise barrier application. For example, in the case of Durisol absorptive layer, the recommended thickness is about 5 cm.

2/ For the range of variables studied, no correlation was found between the porosity of porous concrete materials and their overall sound-absorption (of highway traffic noise).

3/ The use of resonator cavities significantly improves sound-absorption of porous concrete materials. However, their effect on durability, strength and sound transmission must also be considered.

4/ Sealing one face of the porous concrete panels, to achieve resonant absorption, appears to be the most promising method to improve their sound-absorption characteristics.

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Table 1/ Properties of Porous Portland Cement Concrete Samples

Sample No.	Dry Density g/cm^3 [1]	Water Absorption After Boiling, % [1]	Porosity, % of Space	Surface Roughness [2]	A-Weighted Sound-Absorption Coefficient, α_A [3]
1	1.96	15.38	30.1	2	0.17
2	2.02	13.74	27.8	3	0.20
3	2.08	12.30	25.6	4.5	0.21
4	2.01	13.79	27.8	3	0.23
5	2.01	14.19	28.5	4	0.28
6	2.07	12.34	25.6	6	0.28
7	2.03	13.38	27.2	5	0.29
8	2.14	10.92	23.3	7	0.30
9	2.01	13.82	27.8	6	0.31
10	2.15	10.37	22.3	7	0.32

[1] Based on ASTM C 642

[2] Based on a subjective scale 1 to 10.

[3] A-weighted sound-absorption coefficient based on impedance tube measurements.

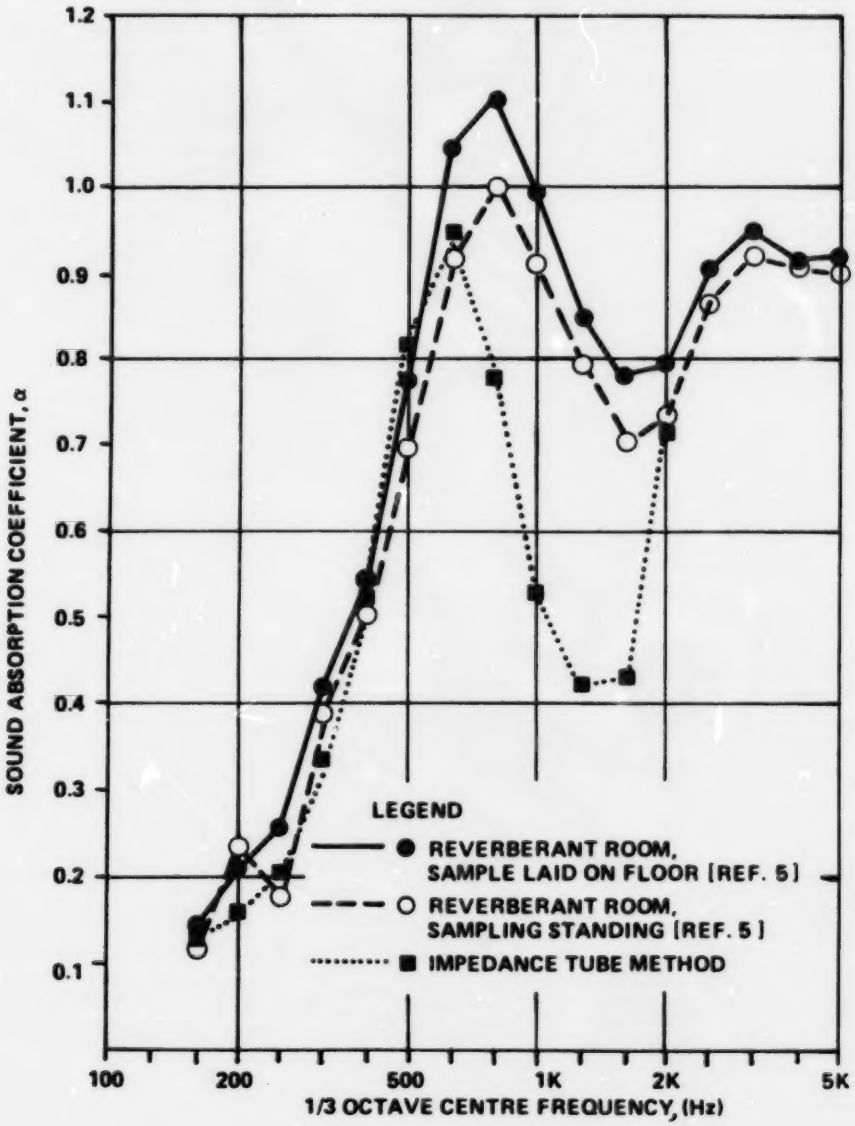

Figure 1/ Absorption Coefficient of Two-Layer Panels (Durisol) Measured by Different Testing Methods

Thickness of Durisol layer 7.5 cm, thickness of concrete backing 1.9 cm

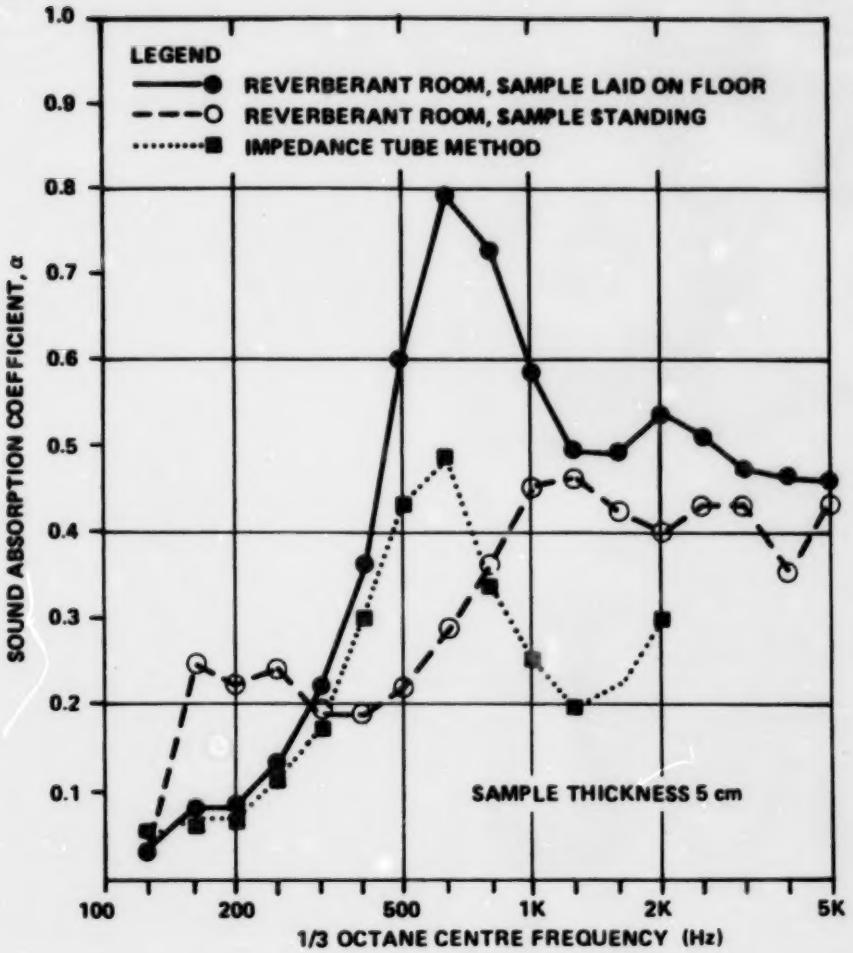

Figure 2/ Absorption Coefficient of One-Layer Porous Concrete Material (Evercrete) Obtained by Different Testing Methods

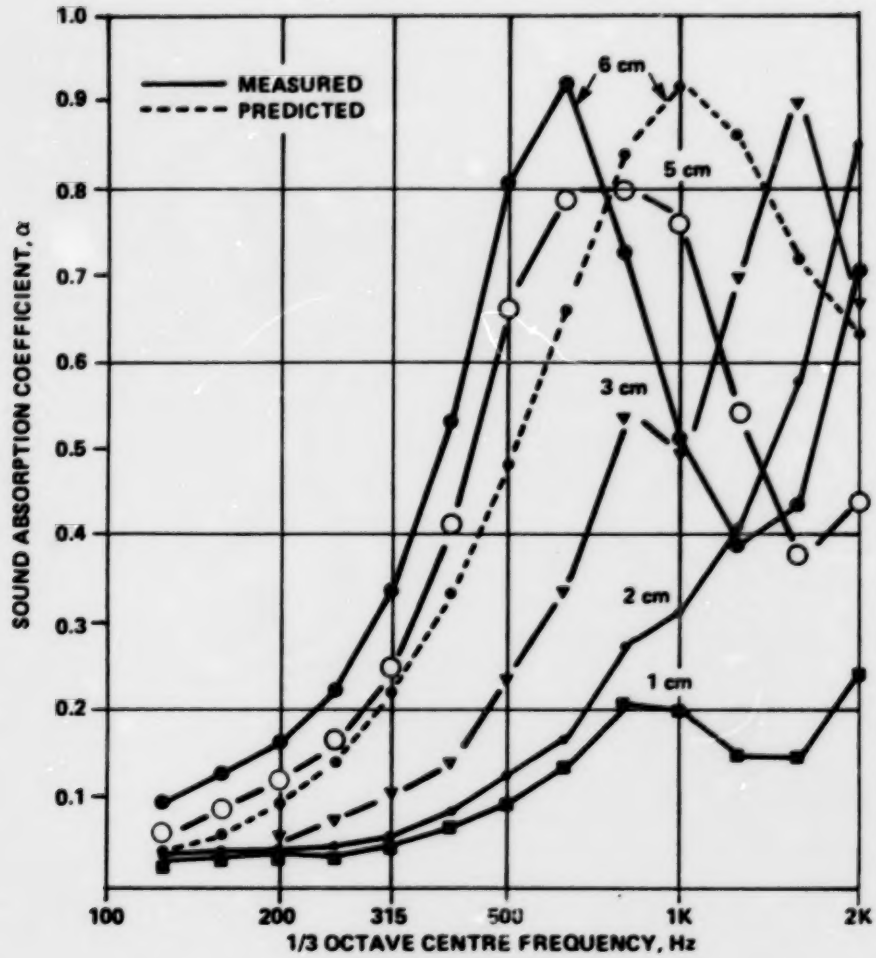

Figure 3/ Absorption Coefficient of Durisol Measured by Impedance Tube Method

Complete panel with concrete backing. Thickness of Durisol layer as indicated. Values assumed for calculations : see Figure 4.

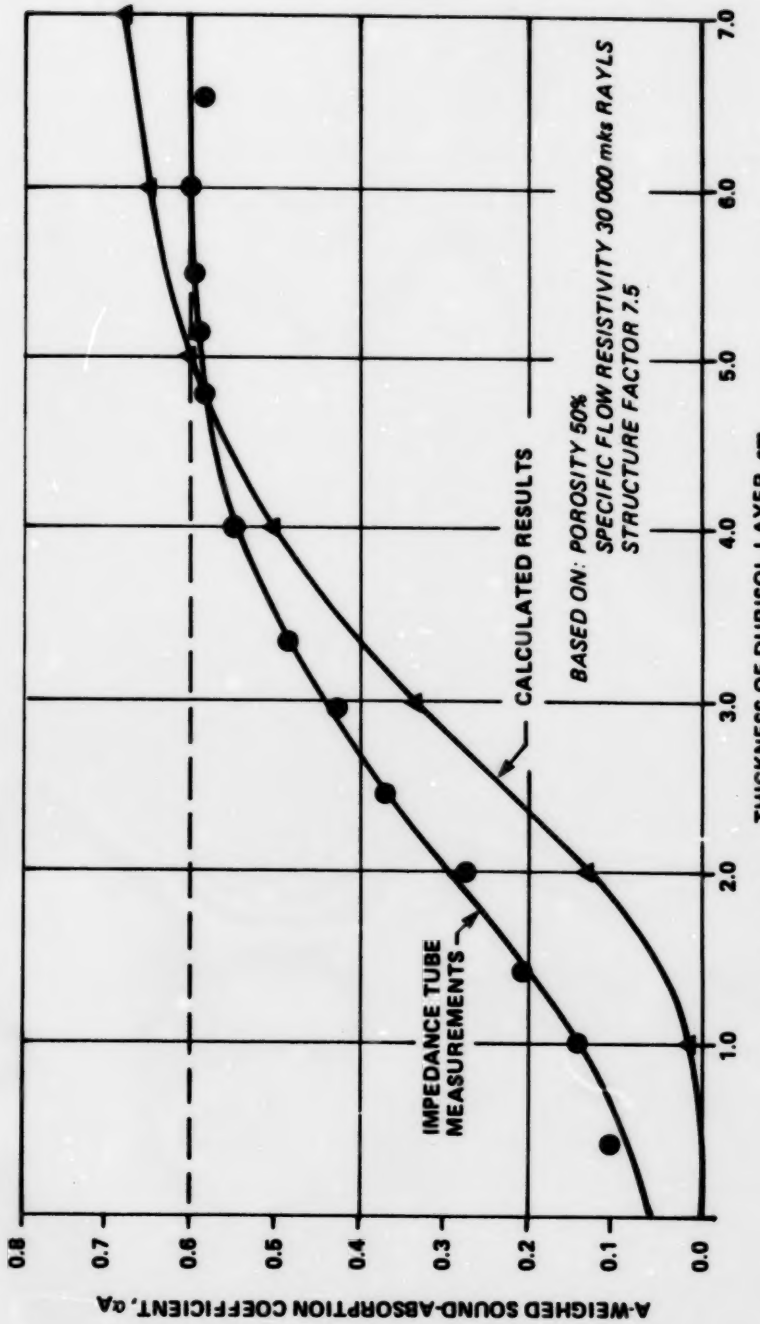

Figure 4/ Influence of Thickness of Durisol Layer on Sound-Absorption Coefficient, α_A

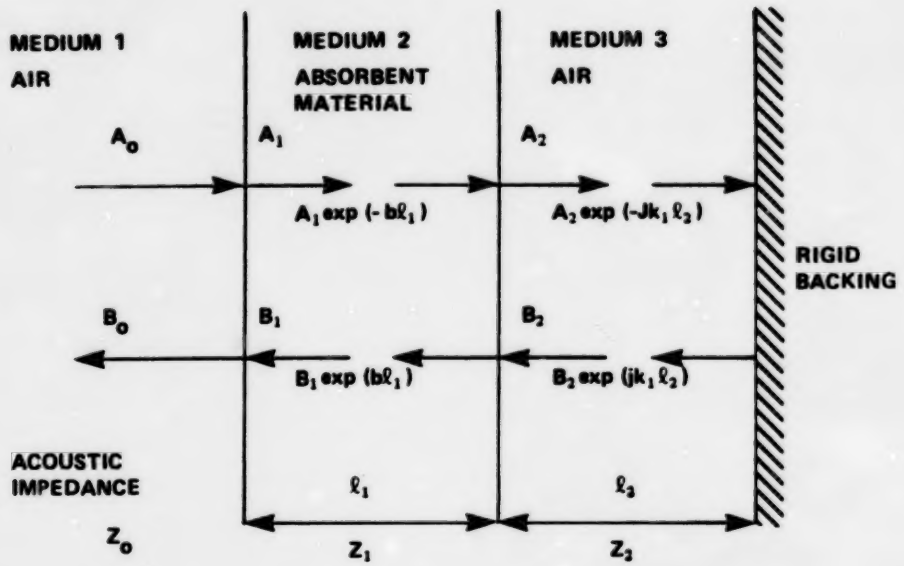

Figure 5/ Sound Wave Propagation

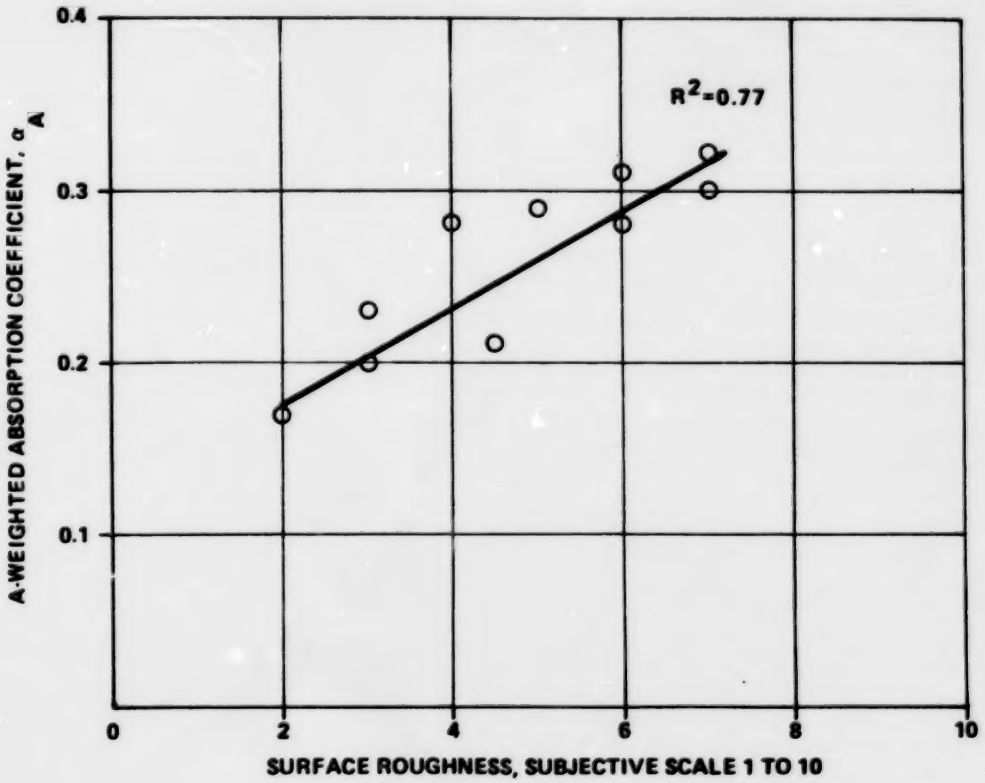

Figure 6/ Relationship Between Surface Roughness and α_A, Porous Concrete

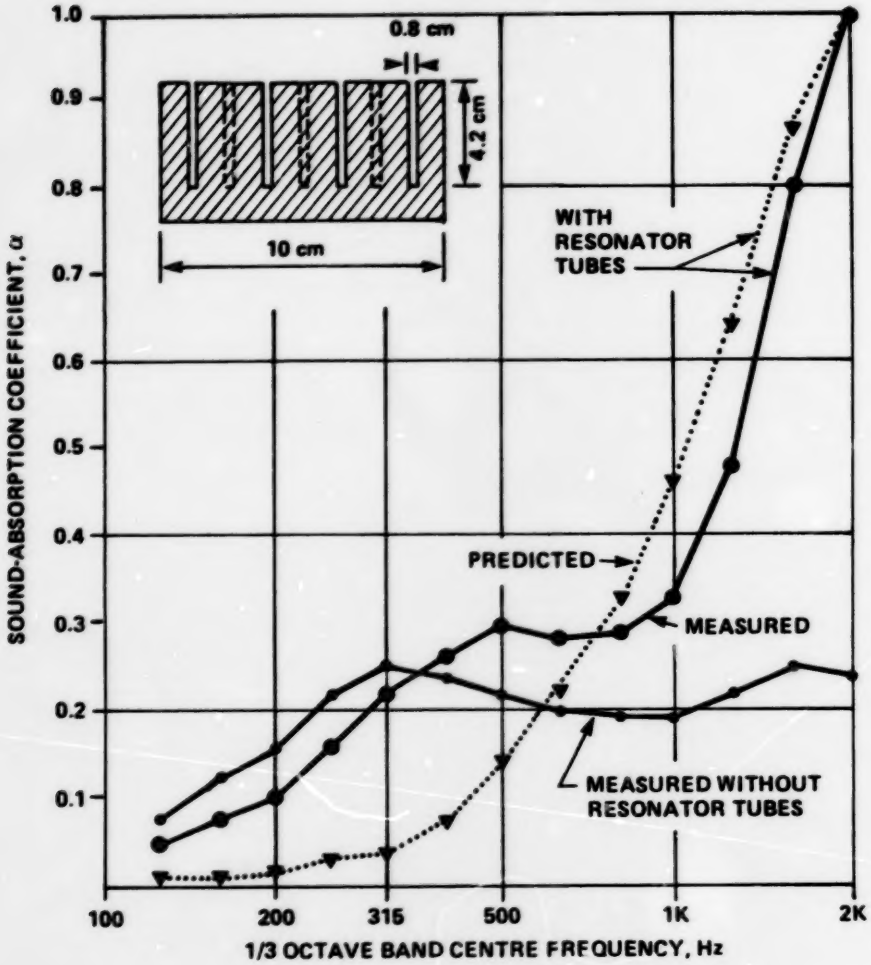

Figure 7/ Sound-Absorption Coefficient for Porous Concrete with 0.4 cm Radius Tube Resonators

Length of resonator tubes 4.2.cm, sample thickness 5.5 cm, 19 resonators in the sample (diameter=10 cm), measured by impedance tube method.

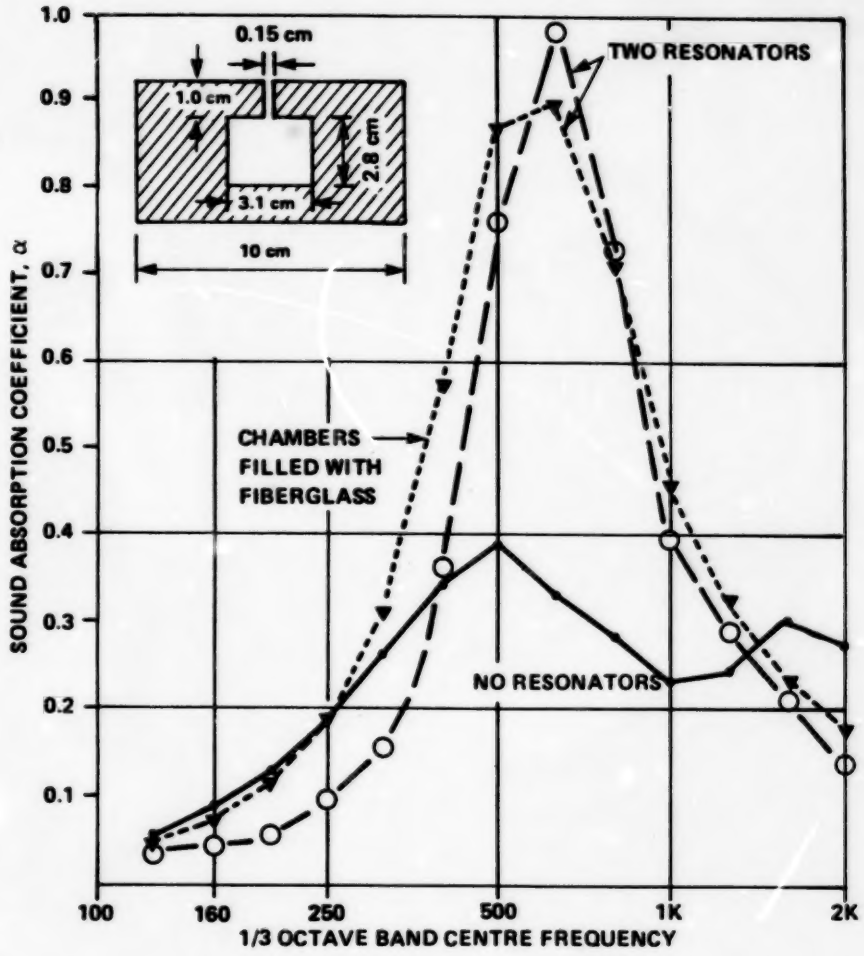

Figure 8/ Absorption Coefficient of Porous Concrete with Helmholtz Slot Resonators

Two slot resonators in a 5 cm radius sample. Calculated resonance frequency 630 Hz. Measured by impedance tube method.

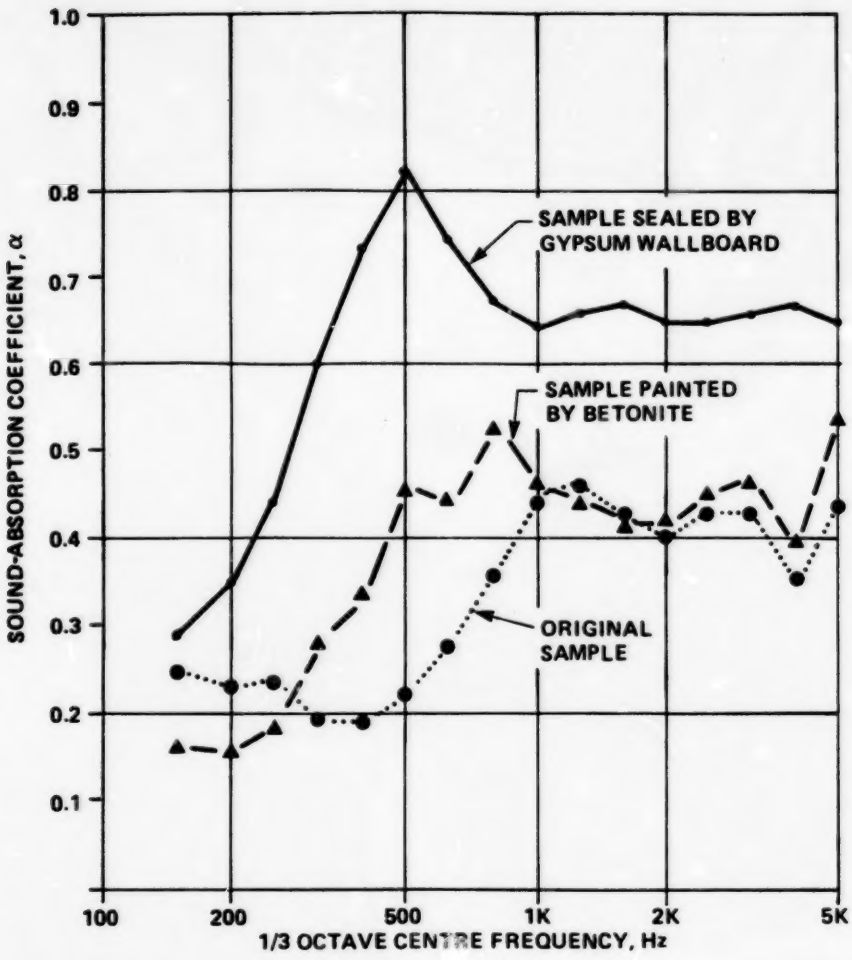

Figure 9/ Effect of Sealing Porous Concrete on Sound-Absorption Measured by Reverberation Room Method

Results shown are for the sample face with highest overall absorption. Thickness of sample 5.0 cm, sample size 3.8 m^2